1 February 2002



Optics Communications 202 (2002) 69-79

Optics Communications

www.elsevier.com/locate/optcom

Target localization in the three-dimensional space by wavelength multiplexing

J.J. Esteve-Taboada^{a,*}, Philippe Réfrégier^b, Javier García^a, Carlos Ferreira^a

^a Facultat de Física, Departament Universitari d'Òptica, Universitat de València, Cl Doctor Moliner, 50, 46100 Burjassot (València) Spain

^b Physics and Image Processing Group, Fresnel Institute, École Nationale Supérieure de Physique de Marseille, Domaine Universitaire de Saint-Jérôme, 13397 Marseille Cedex 20, France

Received 23 July 2001; received in revised form 13 November 2001; accepted 12 December 2001

Abstract

A method to localize a target in the three-dimensional space is presented. Each different position of the target on the depth axis produces, when captured with a CCD camera, an image of a different size on its sensor plane. The size of this image depends only on the distance between the target and the camera. The use of a white light optical correlator that gives us a different response depending on the scale of the input image permits us to know the depth position of the particular target. The obtained results demonstrate the utility of the newly proposed method. © 2002 Published by Elsevier Science B.V.

1. Introduction

The localization of a given object in a threedimensional (3-D) scene is a very important issue in the field of machine vision and object tracking. Most of the localization methods have been devoted to purely digital or computer approaches rather than to optical approaches. The systems (see, for instance, [1,2]) are based on different mathematical algorithms. Thus, for example, in [1] an algorithm to recognize objects in the 3-D space from one two-dimensional (2-D) video image and to localize the objects in all six degrees of freedom is presented. The algorithm is based on storing in the computer a 3-D model of all objects to be recognized. The combination of the location of the detected features in the 2-D input scene with the features of the 3-D computer model allows for obtaining a subspace of possible solutions of the location parameters to be determined.

A direct application of the artificial vision systems of target localization is in the field of road traffic vision (see, for instance, [3,4]). For example, in [3] two algorithms are described, one based on symbolic image features (like line segments), and the other simply based on image intensity gradients. The developed system has three main modules, which are movement detection, vehicle discrimination, and vehicle tracking.

^{*} Corresponding author. Tel.: +34-96-386-4717; fax: +34-96-386-4715.

E-mail address: jose.j.esteve@uv.es (J.J. Esteve-Taboada).

^{0030-4018/02/\$ -} see front matter @ 2002 Published by Elsevier Science B.V. PII: S0030-4018(02)01090-8

To estimate the position of a target in a 3-D scene another approach, based on acoustical signals, can be used: the echo response of an active multibeam imaging system. For instance, in [5], an algorithm which can be used to yield accurate positional estimates for targets is developed. The method refines a least squares residual of the predicted data versus observed data by adjusting the parameters of a set model.

Nevertheless, most of these systems are based on bothersome mathematical algorithms calculated with digital methods, and need fast computers with a lot of storage capability to obtain good results in real time (i.e., smaller than or equal to the video frame rate).

In this paper we introduce an optical method capable of determining the position of a target in a 3-D scene. When capturing the scene with a CCD camera, it is well known that a change in the depth position of an object only causes a change in the size of its image. So we can use a scale estimation optical system (see [6]) to determine the depth position of the target. This optical system is an optical correlator that works with a spectrally broad-band light source. The use of a discriminant filter such as, for instance, the phase-only filter (POF), and the use of a black and white CCD camera as image acquisition system permit us to obtain a detection rank in which the system gives a correlation peak which goes from the visible to the near-infrared electromagnetic spectrum. The estimation process is done simultaneously for different scaled targets. That is, using an input scene composed of different scaled objects (in the case of [6] the rank allowed for the magnification factor is smaller than or equal to 2) we obtained in the correlation plane, as demonstrated in [6], a set of correlation peaks, each one in a different wavelength, indicating the presence of the different scaled targets in the input scene. The key issue here is that this setup multiplexes each different scale of the target in a different wavelength, since each correlation peak has a different color depending on the different scalings of the detected target.

So this method can be used, once the target has been detected (i.e., once the optical system has given a correlation peak in the final plane), to locate the target in the 3-D space, since the obtained correlation peak has a different color depending on the different scales of the target in the input scene, i.e., depending on its different depth positions when capturing this input scene with a CCD camera.

In Section 2 the description of the system is presented: Basic theory is presented in Section 2.1, and in Section 2.2 the design of the filter is explained. In Section 3 simulated results show the utility of the newly proposed method. Finally, in Section 4 the main conclusions are outlined.

2. Description of the system

2.1. Basic theory

Consider an input object placed in a 3-D scene and captured with a CCD camera. This situation is sketched in the upper part of Fig. 1, in which the object is represented by an arrow of height h. As can be seen in this figure, a displacement of the object on the depth axis produces a change in the size of its image in the sensor plane of the camera. Taking as origin of distances the front focal plane of the CCD lens, the magnification factor introduced by the lens for the object placed at a distance p_1 can be written as

$$\beta_1' = \frac{h_1}{h} = -\frac{f}{p_1},\tag{1}$$

f being the front focal length of the lens. A similar expression holds for the same object placed at a distance p_2 :

$$\beta_2' = \frac{h_2}{h} = -\frac{f}{p_2}.$$
 (2)

For later use, from Eqs. (1) and (2) it is easy to obtain the ratio between two well-determined scales of the object:

$$\frac{\beta_2'}{\beta_1'} = \frac{h_2}{h_1} = \frac{p_1}{p_2}.$$
(3)

But in Eqs. (1) and (2) the origin for the distances p_1 and p_2 is not the same, because the lens has changed its position in order to focus the second object, remaining thus unchangeable the position of the image plane. So, Eq. (3) is only valid for a



Fig. 1. Whole experimental optical setup. When dealing with far objects the variation for d is only about a few tenths of mm.

limited interval of object positions, for which the displacement of the focusing lens can be neglected. To obtain the limits of this interval we consider first the object placed at infinity. In this case the distance between the lens and the CCD sensor plane is equal to the focal length of the lens. If we now consider that the object comes near the CCD camera up to a distance p, the focusing lens has to be displaced far away from the CCD sensor plane in order to focus the object at the same image plane. Using Newton's geometrical optics equation the expression for this displacement holds:

$$\Delta_{\rm L} = \frac{-f^2}{p}.\tag{4}$$

Taking as a criterion that this displacement could be neglected if it is less than the 1% of the front focal length of the lens, the object can be assumed to be focused at the same image plane without changing the position of the lens if the distance

|p| > 100f.

Just as an example, considering a 50 mm focal lens, the limited interval of object positions if we want to consider fixed the position of the lens is $\Delta_{\rm O} = (-\infty, -5)$ m. As we will see later, the interval of object positions (or analogously, the interval of scale factors) that the system is able to detect depends on the interval of wavelengths in which the detector works, so the interval $\Delta_{\rm O}$ is large enough when considering the inherent scale factor limitation of the method.

The fact that a displacement of the object on the depth axis produces a change in the size of its image, together with the use of a system capable of discerning different scales of an object, can be utilized to determine the 3-D position of a given target. Thus, if the output of the CCD camera which is capturing the 3-D scene is presented as the input image on the system capable of discerning different scales of the target (multiplexing each different scale in a different wavelength), we can obtain unequivocally the 3-D position of a given target.

The system that gets detection of different scaled targets by wavelength multiplexing is the one introduced in [6]. The optical setup of this system is sketched in the lower part of Fig. 1. It can be divided into two parts: the first one, the front part up to the plane (x_3, y_3) , is a classical

convergent correlator [7]. The input scene is described by the function $s(x_1, y_1)$, and the matched filter is adapted to the target $t(x_1, y_1)$. The mask at plane (x_3, y_3) selects only the term corresponding to the correlation between the input scene and the target. So at this plane, when illuminating with light of wavelength λ , we have (except for constant factors)

$$U(x_3, y_3; \lambda) = \left[t \left(\frac{\lambda_0 z_0 x_3}{\lambda z_2}, \frac{\lambda_0 z_0 y_3}{\lambda z_2} \right) * s \left(\frac{z_1 x_3}{z_2}, \frac{z_1 y_3}{z_2} \right) \right] \\ \otimes \delta(x_3, y_3 - \alpha \lambda z_2), \tag{5}$$

where the symbol * denotes the cross-correlation operation and the symbol \otimes denotes the convolution operation. We have assumed that the filter matching to the target $t(x_1, y_1)$ is recorded in the usual way with light of wavelength λ_0 and with a plane wave incident at an angle θ as reference beam, so the carrier frequency is $\alpha = (\sin \theta / \lambda_0)$. As can be seen, if the system is illuminated with a white-light point source (WLPS), the lateral position of the correlation term along the Y axis is linearly proportional to the wavelength of the illumination beam. Thus the second part of the optical setup is a system that compensates the chromatic dispersion that appears in the correlation plane (x_3, y_3) . The complete mathematical analysis of this optical system is done in [6]. The final expression for the complex amplitude distribution at plane (x_5, y_5) is

$$U(x_5, y_5; \lambda) = t \left(\frac{\lambda_0 z_0 M x_5}{\lambda z_5}, \frac{\lambda_0 z_0 M y_5}{\lambda z_5} \right)$$
$$* s \left(\frac{z_1 M x_5}{z_5}, \frac{z_1 M y_5}{z_5} \right), \tag{6}$$

M being the magnification factor introduced by the lens L_3 between the planes (x_2, y_2) and (x_4, y_4) .

In order to show the scale invariance property of the system consider that in the input scene we have a scaled version of the target, for instance, s(x, y) = t(x/m, y/m). In this case, at plane (x_5, y_5) we will have a correlation peak for the wavelength of the WLPS that fulfills [see Eq. (6)]

$$\lambda = \frac{\lambda_0 z_0 m}{z_1}.\tag{7}$$

This last equation shows that the wavelength that provides the correlation peak is linearly proportional to the scale factor of the input scene. That is, each scaled version of the target, or analogously, each different position of the target on the depth axis when capturing the scene with a CCD camera, is detected in the final plane with a correlation peak of different wavelengths. This fact, together with the 2-D shift-invariant property of the optical correlator, permits us to obtain unequivocally the 3-D position of the target in the 3-D scene.

2.2. Filter design

Esteve-Taboada et al. demonstrated in [6] the detection properties of the system sketched in the lower part of Fig. 1. We can interpret this system in two different ways: first, if we do not consider the wavelength information in the correlation plane (that is, if we capture this correlation plane with a black and white CCD camera), the system is a scale-invariant correlator, which gives a correlation peak independently of the scale of the target (within a determined range of scales). Second, considering in the correlation plane the wavelength information (i.e., capturing it, for instance, with a color sensitive device), we can interpret the system as a scale-variant correlator, in the sense that it gives a correlation peak of different colors depending on the scale of the target in the plane $(x_1, y_1).$

In this system, the sensitivity of the filter to scale changes determines the chromatic characteristics of the correlation peak. Consider, for instance, a scale-invariant filter. Having in mind the relation between wavelength and scale that matches the filter [see Eq. (7)], this filter will provide a broad-band correlation peak, because multiple wavelengths will match the filter at the corresponding scales. The color of the correlation peak is unsaturated (close to white), and will not change significantly for different scales of the target. On the other hand, a highly selective filter will produce a monochromatic correlation peak, because only one wavelength will match the filter. This case does permit us to derive the scale of the target directly from the color of the peak (just by determining its wavelength). Between these two extreme cases, many degrees of scale variance are possible. The preferred case will depend on how the color information is taken from the correlation plane.

From a technical point of view, to capture all the chromatic information that appears in the correlation plane would be a very difficult task. It would be necessary to detect all the wavelengths using, for example, a large set of interferential filters or a camera with a high number of chromatic channels. As stated above, in this paper we propose to capture the correlation plane using a color CCD camera which has three chromatic channels (RGB). We have experimentally measured the joint spectral response of the WLPS (a 250 W Xenon lamp focused onto a pinhole) and the color CCD camera (model Sony DXC-950P). The result is the one plotted in Fig. 2. Imagine now that we use a filter with a high scale selectivity, such as POF, to perform the correlation operation. Say that the filter gives a narrow peak when representing it along the wavelength axis. Just as an example consider that the width of the peak is 30 nm. If we have two closely scaled targets, one with a scale factor corresponding to the wavelength [see Eq. (7)] 510 nm, and the other with a scale factor corresponding to 540 nm, it is clear that when taking these two correlation peaks with the color camera, all the chromatic information will be taken mainly in the green channel (see Fig. 2). Thus,



Fig. 2. Joint spectral response of the WLPS and the color CCD camera.

the two peaks will have small or null differences in their RGB color components.

Assuming that the width of the correlation peak on the wavelength axis is wide enough to assure that any scale will contribute in more than one chromatic channel, the scale of the target can be obtained without ambiguity from the RGB color components of the correlation peak. One possible way to deal with the RGB components is to use a classic diagram of chromaticity. Plotting the chromatic coordinates of the different correlation peaks in this diagram allows us to obtain a curve (which we will name as "color curve") that provides unequivocally the information of the scale of the target, and therefore, its position on the depth axis.

To perform the correlation operation we have used a minimum average correlation energy (MACE) filter [8–10] adapted to a relatively close scaled target. Depending on the close scaled targets used to make the MACE filter, one can control at will the width of the correlation peak in the wavelength axis, and so, the appearance of the color curve which has to give us unmistakably the position of the target on the depth axis. In this case the color information will be taken by the camera in more than one chromatic channel. But it is clear that if the correlation peak is too wide, the color curve in the chromaticity diagram will be smaller (and closer to white light), giving thus a low precision in the depth localization. The optimum way is to find a trade-off between the width of the correlation peak (i.e., between the close scaled targets used to make the MACE filter) and the general aspect of the color curve in the chromaticity diagram.

In order to illustrate these ideas consider the traffic signal shown in Fig. 3. As the different wavelengths play the role of scaling with different values the Fourier transforms (FTs) of the system, we can simulate the behavior of the WLPS using different scale factors in the FTs within a defined interval (in Section 3 we provide the numerical details of this simulation). We consider as input object a scaled version (with scale factor m = 0.9) of the signal shown in Fig. 3. For each different wavelength (that is, each different scale factor in the Fourier plane) we obtain the



Fig. 3. Input object.

intensity of the correlation peak obtained between the input object and the considered filter. The plot in Fig. 4(a) shows the intensity of the correlation peak versus the different wavelengths (different scale factors in the simulation) when a POF is used. In this case, this plot means that the scaled input object (m = 0.9) is detected in the final plane by a green correlation peak (the maximum of this correlation peak appears in 523 nm). As stated above, the obtained peak in this plot is too narrow for the purpose of this paper, because a close scaled target (for example, with m = 1.0) will provide another peak with small or null differences in its RGB chromatic components captured by the color camera when comparing with the previous one. Instead, when using an MACE filter one can obtain the peak plotted in Fig. 4(b). We can see that the width of this peak in the wavelength axis is bigger than in the previous case, so the differences between the chromatic coordinates of the correlation peaks when considering two close scaled targets will be meaningful, as any scale will contribute in more than one chromatic channel.

3. Results

As explained above, in the optical setup the different wavelengths play the role of scaling with different values the FTs of the system, so we can simulate the optical behavior of the system using



Fig. 4. Intensity of the correlation peak as a function of the wavelength when using (a) a POF, and (b) an MACE filter.

different scale factors in the FTs in a determined interval corresponding with the interval of wavelengths that the color CCD camera can detect.

The experimentally measured joint spectral response of the WLPS and the color CCD camera is plotted in Fig. 2. We can see that the interval of wavelengths detected by the camera goes from 430 to 730 nm. Even so we avoid the tails in the spectral response which give us a poor intensity correlation peak and consider the range of wavelengths from 445 to 680 nm. Choosing a value for

 λ_0 , for instance, as equal to 582 nm in Eq. (7), this range of wavelengths is equivalent (if we assume $z_0 = z_1$) to a range of scales of the target from 0.765 to 1.168. Note that another value for the wavelength λ_0 only changes the particular values of the minimum and maximum scales for the target, but does not change the ratio between them, which is the important value in our case. Therefore in order to simulate the broad-band light source we consider 235 wavelengths within the range [445, 680] nm (1 nm accuracy), and so we have to divide the range of scale factors into 235 parts.

The considered target for obtaining the simulated results is the traffic signal shown in Fig. 3. Now, we want to obtain the color curve that permits us to locate a defined object in the 3-D scene depending on the color of the obtained correlation peak. So, the set of training objects is composed of many scaled versions of the target with scale factors within the range [0.765, 1.168]. The MACE filter has been adapted to the following three objects: the target scaled with a scale factor of 0.95, the target scaled with a scale factor of 1.05, and the target without scaling.

For each object of the training set we scale its FT correlatively in one of the 235 values of the scale factor range stated above, we weight each of these images by the corresponding value of the spectral response shown in Fig. 2, multiply by the MACE filter, and obtain the square modulus of the inverse FT of the product. The sum of all the obtained images (which corresponds to the optical incoherent sum of the different wavelengths) allows for getting a correlation peak that has a different color for every different object of the training set. Each different color is characterized by different chromatic components RGB which we suppose follow the standard of the National Television Systems Committee (NTSC). From these RGB-NTSC coordinates we obtain the corresponding $(x_{\text{CIE}}, y_{\text{CIE}})$ color coordinates [in the standard of the Commission Internationale de l'Eclairage (CIE)], in order to plot each color in the CIE chromaticity diagram. The CIE color coordinates can be obtained from the RGB-NTSC coordinates using the following conversion matrix [11]:

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix}_{\text{CIE}} = \begin{pmatrix} 0.607 & 0.174 & 0.200 \\ 0.299 & 0.587 & 0.114 \\ 0.000 & 0.066 & 1.116 \end{pmatrix} \begin{pmatrix} R \\ G \\ B \end{pmatrix}_{\text{NTSC}},$$
(8)

and the following relations:

$$x_{\text{CIE}} = \left(\frac{X}{X+Y+Z}\right)_{\text{CIE}},$$

$$y_{\text{CIE}} = \left(\frac{Y}{X+Y+Z}\right)_{\text{CIE}}.$$
(9)

In Fig. 5 we show the color curve obtained for the set of the training objects. As indicated with some examples, each point corresponds to a different value of the scale factor for the target within the interval of scales stated above. The central point denotes the standard CIE white color, which has as color coordinates (0.33, 0.33). We can see how each different value of the scale of the target, or analogously, each different position of the target on the depth axis when capturing it with a CCD camera, corresponds to a different point in the color curve plotted in the CIE chromaticity diagram. Thus we are able to estimate the depth position of the target through the color coordinates of the corresponding correlation peak.



Fig. 5. Color curve obtained in the chromaticity diagram for the input target shown in Fig. 4. Some of the corresponding scale factors are indicated.

As stated above, a range of scales is equivalent to a range of depth positions for the target [see Eq. (3)]. We consider the reference distance p_0 that provides an image of the object onto the sensor plane of the camera of size h_0 , which corresponds with a scale factor of m = 1. For the interval of scales [0.765, 1.168] the corresponding ratio of distances may be obtained following Eq. (3) as

$$\frac{h_1}{h_2} = \frac{m_1 h_0}{m_2 h_0} = \frac{1.168}{0.765} = \frac{p_2}{p_1} = 1.53.$$
(10)

Let us see now an example of 3-D localization. For the sake of simplicity we will consider that the object is placed sufficiently far from the lens. In this case, whereas in Fig. 1 one may approximate $p_1 + f \simeq p_1$ and $p_2 + f \simeq p_2$, the size of the corresponding images h_1 and h_2 can be obtained, following the sketch shown in this figure, as

$$\tan \alpha_1 = \frac{h}{p_1} = \frac{h_1}{d},\tag{11}$$

and thus,

$$h_1 = \frac{hd}{p_1},\tag{12}$$

d being the distance between the lens of the CCD camera and its sensor plane. Analogously,

$$h_2 = \frac{hd}{p_2},\tag{13}$$

where we have taken into account that when dealing with far objects the variation for d is negligible (about a few tenths of mm). As can be verified, in this case of far objects the ratio between two well-determined scales of the object holds fulfilled. Consider that for these two different depth positioned targets we obtain in the color curve that their different scaled images in the input scene correspond, for instance, with the scale factors $m_1 = 0.79$ and $m_2 = 1.06$. Using Eq. (12) we can obtain the different depth positions for the targets

$$p_1 = \frac{hd}{h_1} = \frac{hd}{m_1 h_0} = \frac{hd}{m_1 (hd/p_0)} = \frac{p_0}{0.79},$$
(14)

and analogously

$$p_2 = \frac{p_0}{1.06}.$$
 (15)

Assuming, for instance, that the lateral magnification factor of the camera for the object placed at a distance p_0 is $|\beta'_0| = (h_0/h) = 0.005$ (which means that for an object of size 60 cm its image onto the sensor plane of the camera has a size of 3 mm), and considering that the distance d between the camera lens and the CCD sensor plane is equal to 50 mm, the distances p_1 and p_2 yield:

$$p_1 = \frac{p_0}{0.79} = \frac{hd}{0.79h_0} = \frac{d}{0.79|\beta'_0|} = 12.66 \text{ m},$$
 (16)

and

$$p_2 = \frac{p_0}{1.06} = \frac{d}{1.06|\beta_0'|} = 9.43 \text{ m.}$$
 (17)

As it has been shown, it is easy to obtain the depth positions of the targets once they have been located in the color curve of the chromaticity diagram. As stated above, the most important limitation of the system comes from the inherent dependence on the interval of wavelengths detected by the camera, and not from the Δ_0 interval needed to maintain unchangeably the position of the camera lens.

We now consider the input scene shown in Fig. 6. It is composed of different scaled versions of the traffic signal used as target (relative to the target



Fig. 6. Input scene used to test the discrimination ability of the system.



Fig. 7. Chromatically compensated correlation output plane for the optical system shown in Fig. 1, considering as input the scene shown in Fig. 6.

shown in Fig. 3, the different scale factors are 0.79, 0.91 and 1.09), and of different scaled versions of another traffic signal used to test the discrimination ability of the system. The scaled versions of the target have been selected from the whole set of training objects that was previously obtained. The corresponding chromatically compensated correlation plane which could be obtained in the plane of the color CCD camera is shown in Fig. 7. We can observe three correlation peaks which point out the presence of the different scaled versions of the target. The color of each peak indicates to us the scale factor of the target detected, or analogously, the depth position of the traffic signal. Thus, the peak named with letter (a) is a dark-blue one (see Fig. 8) [its RGB-NTSC chromatic coordinates are (4, 29, 174)], the (b) peak is a green one **[**with **RGB-NTSC** chromatic coordinates (25, 255, 28)], and the (c) peak is a light-red one **[**with **RGB-NTSC** chromatic coordinates (185, 14, 0)]. The discrimination ability of the system is very high since these three correlation peaks allow a clear discrimination with the cross-correlation terms that appear due to the other traffic signals.

Finally, we study the noise robustness of the system. We consider two different types of noise:



Fig. 8. Chromatic coordinates obtained in the correlation peak for each of the targets shown in Fig. 6.

first, a white (non-correlated) uniform additive noise with zero-mean and standard deviation equal to 29.4 (the maximum and minimum gray levels of the original image are equal to 255 and 0, respectively) [the noisy input object is shown in Fig. 9(a)], and second, a 15% salt and pepper noise







Fig. 9. (a) Object corrupted with a white (non-correlated) uniform additive noise with zero-mean and standard deviation equal to 29.4. (b) Intensity of the correlation peak as a function of the wavelength when using an MACE filter. The dotted line corresponds to the noisy object shown in (a), and the continuous line corresponds to the object shown in Fig. 3.

(which means that the 15% of the pixels in the image has been changed) [see Fig. 10(a)]. To show the influence of the noise present in the input scene we consider as input objects, as was done before for the object shown in Fig. 3, a scaled version (with scale factor m = 0.9) of the objects shown in Figs. 9(a) and 10(a). For each different wavelength (or analogously, each different scale factor in the Fourier plane) we obtain the intensity of the correlation peak between these input objects and the

Fig. 10. (a) Object corrupted with a 15% of salt and pepper noise (which means that the 15% of the pixels in the image has been changed). (b) Intensity of the correlation peak as a function of the wavelength when using an MACE filter. The dotted line corresponds to the noisy object shown in (a), and the continuous line corresponds to the object shown in Fig. 3.

MACE filter. In Figs. 9(b) and 10(b) we show the results (dotted lines) for the objects shown in Figs. 9(a) and 10(a), respectively, in comparison with the previously obtained result for the object without noise (continuous lines). As can be seen, our system has a very good noise robustness, since the presence of these two kinds of noise in the input scene only provokes a diminution in the intensity value of the correlation peak for each wavelength, but it does not change the wavelengths of detection

of the corresponding target, that is, the chromatic coordinates in which the target is detected.

4. Conclusions

In this section, we have presented a new method to localize targets in the 3-D space that is based on an optical correlator that works with white-light illumination. Considering an object in a 3-D scene which is captured by a CCD camera, each different position of this object on the depth axis produces an image on the sensor plane of the camera of a different size, which only depends on the depth position of the object. Then, using an optical correlator that gives us a different response depending on the scale of the input object, we can recognize the depth position of the particular target. In the optical correlator that we have used each scaled version of the target, or analogously, each different position on the depth axis, is detected with a correlation peak of different wavelengths. Plotting the chromatic coordinates of the different obtained correlation peaks in a chromaticity diagram allows us to obtain a color curve that provides unequivocally the position of the target on the depth axis.

In spite of our system multiplexes each different depth position of the target in a different wavelength, and all of these wavelengths are added incoherently in the final correlation plane, we are able to simultaneously detect different depth positioned targets in the same input scene.

Acknowledgements

José J. Esteve-Taboada acknowledges a grant from the Conselleria de Cultura, Educació i Ciència (Generalitat Valenciana). Javier García acknowledges a grant from the Spanish Secretaría de Estado de Educación y Universidades. The authors thank the DGR of the Generalitat de Catalunya (project XT99-0014) for the financial support.

References

- G. Häusler, D. Ritter, Comput. Vision Image Understanding 73 (1999) 64.
- [2] Z.X. Li, J.B. Gou, Y.X. Chu, IEEE Trans. Robot. Autom. 14 (1998) 864.
- [3] T. Tan, Opt. Eng. 37 (1998) 202.
- [4] T.N. Tan, G.D. Sullivan, K.D. Baker, Int. J. Comput. Vision 27 (1998) 5.
- [5] J.S. Jaffe, J. Acoust. Soc. Am. 105 (1999) 3168.
- [6] J.J. Esteve-Taboada, J. García, C. Ferreira, Appl. Opt. 39 (2000) 1268.
- [7] J.W. Goodman, Introduction to Fourier Optics, second ed., Electrical Engineering Series, McGraw-Hill, Singapore, 1996.
- [8] A. Mahalanobis, B.V.K. Vijaya Kumar, D.P. Casasent, Appl. Opt. 26 (1987) 3633.
- [9] A. Mahalanobis, D.P. Casasent, Appl. Opt. 30 (1991) 561.
- [10] Ph. Réfrégier, Opt. Lett. 15 (1990) 854.
- [11] W.K. Pratt, Digital Image Processing, second ed., Wiley, New York, 1991.